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Shadow Flicker Analysis

for the

North Atlantic Wind to Hydrogen Project

Prepared For

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1.0 Introduction

North Atlantic Refining Corp. (North Atlantic) is proposing the development of a wind to hydrogen project (the Project) on the Isthmus of the Avalon Peninsula, Newfoundland and Labrador (NL). This initiative aims to harness renewable wind energy for large-scale hydrogen production, supporting global decarbonization efforts. The Project will involve the development, construction, operation, and eventual decommissioning of a Wind Farm, a 324 MW wind energy development comprising up to 45 wind turbines located throughout 55 potential sites, each with an approximate rated power of 7.2 MW, on provincial Crown lands designated for Green Energy Reserve. The wind farm will be used to generate electricity for the proposed Hyrdrogen Generation Plant which is planned to be built in Come By Chance.

Large development projects such as the North Atlantic Wind to Hydrogen Project are subject to an Environmental Assessment through the Environmental Protection Act. This process is designed to ensure that projects proceed in an environmentally acceptable manner by:

- Protecting the environment and the quality of life of the people of the province; and,
- Facilitate wise management of the natural resources of the province.

The development of wind energy projects requires careful consideration of the impact of wind turbines on existing residents of the area. One of these potential impacts is shadow flicker. The rotating blades of a wind turbine create moving shadows known as shadow flicker which is noticeable when a person is located in close proximity to a turbine. The potential impact depends on the time of year, the physical characteristics of the wind turbine, the orientation of the blades relative to the sun, the presence of wind and of course, the presence of sunlight.

The following report summarizes the results of shadow flicker modeling which will be incorporated into the Newfoundland and Labrador Environment Assessment Registration Document.

2.0 Methodology

A total of 55 proposed turbine locations were provided by the client and the positions are summarized in Table 1. The model specific parameters of the proposed turbines are shown in
Table 2.

Table 1: Proposed Turbine Positions.

Name	Easting (m) *	Northing (m)
DNV-04	287,873	5,308,155
DNV-05	289,560	5,307,691
DNV-06	288,720	5,306,198
DNV-07	288,509	5,305,624
DNV-09	289,975	5,305,880
DNV-10	290,374	5,306,685
DNV-11	291,297	5,306,424
HAT-04	290,603	5,305,440
HAT-05	289,750	5,305,082
HAT-06	290,867	5,304,076
HAT-07	291,378	5,303,771
HAT-08	288,698	5,303,413
HAT-09	287,729	5,302,859
HAT-10	288,654	5,302,797
HAT-11	287,943	5,302,384
HAT-12	290,429	5,302,978
HAT-13	291,707	5,302,566
HAT-14	292,595	5,302,240
HAT-15	288,252	5,301,936
HAT-16	291,402	5,301,692
HAT-17	290,341	5,301,683
HAT-18	292,039	5,301,627
HAT-19	292,959	5,301,589
HAT-20	288,761	5,301,579
HAT-21	289,567	5,301,563
HAT-22	288,182	5,301,088
HAT-23	293,000	5,301,056
HAT-24	288,900	5,300,991

Name	Easting (m) *	Northing (m)
HAT-25	290,204	5,300,863
HAT-26	289,187	5,300,576
HAT-27	292,043	5,300,481
HAT-28	292,721	5,300,392
HAT-29	290,181	5,300,213
HAT-30	290,638	5,299,912
HAT-31	293,101	5,299,890
HAT-32	289,320	5,299,759
HAT-33	291,192	5,299,565
HAT-34	289,739	5,299,433
HAT-35	292,472	5,299,343
HAT-36	290,704	5,299,057
HAT-37	289,742	5,298,897
HAT-38	292,839	5,298,816
HAT-39	291,265	5,298,671
HAT-40	291,970	5,298,603
HAT-41	290,465	5,298,222
HAT-42	291,758	5,298,006
HAT-43	290,931	5,297,764
HAT-44	291,204	5,297,330
HAT-45	290,450	5,297,123
HAT-46	291,294	5,296,643
HAT-47	290,559	5,296,631
HAT-48	289,089	5,304,705
HAT-49	290,845	5,302,603
HAT-50	292,196	5,299,748
HAT-51	290,963	5,300,465

* UTM, WGS84, Zone 22N

Table 2: Turbine Specifications.

Item	Specification
Manufacturer	Vestas
Model	V162-7.2
Hub Height	119 m
Rotor Diameter	162 m
Operation Mode	Full Power
Rated Power Output	7,200 kW

2.1 Shadow Flicker Analysis

A shadow flicker analysis was completed using WindPro 4.1.273 which provides a comprehensive suite of wind farm design and modeling software. The shadow flicker analysis was based on developing a theoretical and realistic scenario that provides an understanding of the extent of shadow flicker because of the proposed turbines.

2.2 Theoretical Case

In this scenario, a bare earth model was considered in the analysis. Potential shadowing objects such as forests, trees and outbuildings were not included in the analysis. This scenario provides an understanding of the maximum amount of shadow flicker expected to be experienced at the modeled receptors under the following conditions:

- The sun shines 100% of the time when it is above the horizon.
- The turbine rotor is always perpendicular to the sun.
- Shadow flicker starts as the sun moves above 3 degrees from the horizon.
- The shadows dissipate at a maximum distance from the blade because of atmospheric conditions and light diffusion, and.
- The rotor blades are always spinning.

The total length of the shadow influence in the atmosphere is calculated from the physical dimensions of the turbine blade. In this analysis, the maximum shadow distance for the V162-7.2 was calculated to be 2,044 m.

Most jurisdictions around the globe consider a maximum of 30 hours of shadow flicker per year and a maximum of 30 minutes per day as the threshold parameters used to define the acceptable level of shadow flicker from wind projects. These levels originate from Europe and are designed to reduce annoyance at neighboring dwellings. Recently, the government of Newfoundland and Labrador passed a Project Release Order (Regulation 18/24) which defines the maximum level of shadow flicker as 30 minutes per day or 30 hours per year.

2.3 Realistic Case

The realistic case was modeled by incorporating site specific monthly sunshine probabilities into the analysis. This procedure provides a better understanding of what the real world conditions are expected to be like at each of the modeled receptors.

Statistical monthly sunshine data were used to provide a realistic condition for calculating shadow flicker. The realistic scenario was modeled using monthly sunshine probabilities obtained from the closest coastal observatory at St. John’s, Newfoundland. The monthly daily sunshine hours used in the analysis are shown in Table 3.

Table 3: Monthly Average Sunshine Hours for St. Johns Airport, Newfoundland (CYYN).

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Average Daily Sunshine Hours	2.39	3.16	3.33	3.84	5.23	6.23	7.65	6.13	4.66	3.46	2.47	1.97

2.5 Shadow Receptors

A total of 96 receptors were identified and modeled in this analysis. Receptors were identified through the public consultation process and using satellite/aerial imagery to locate buildings that can be considered as dwellings. Two pseudo receptors (areas of interest that do not have buildings) were modelled based on comments from the public (receptor AE & BX). Buildings were assumed to have windows facing in all directions. This modeling approach is referred to as 'greenhouse mode' and ensures that the orientation of individual receptor windows are not a factor in estimating shadow flicker.

Table 4 shows the locations of the 96 receptors used in the analysis.

Table 4: Shadow Flicker Receptor Physical Coordinates.

ID	Easting (m) *	Northing (m)	Elev. (m)
A	294,633	5,307,782	12.4
B	294,693	5,307,841	5.8
C	293,054	5,307,933	4.3
D	291,626	5,308,804	13.4
E	291,699	5,308,849	12.5
F	291,663	5,308,894	28.5
G	291,769	5,308,937	10.4
H	291,804	5,308,936	6.9
I	291,920	5,308,888	4.9
J	291,895	5,308,954	13.3
K	291,824	5,308,993	8.9
L	290,325	5,308,632	12.1
M	290,758	5,309,018	2.5
N	290,763	5,309,139	11.8
O	290,719	5,309,233	2.4
P	290,473	5,309,413	7.5
Q	290,533	5,309,399	9.5
R	290,433	5,309,444	8.5
S	290,392	5,309,469	14.1
T	290,358	5,309,489	11.9
U	290,225	5,309,632	6.2
V	290,205	5,309,644	4.1
W	290,067	5,309,548	4.0

ID	Easting (m) *	Northing (m)	Elev. (m)
X	289,636	5,309,524	8.0
Y	289,684	5,309,504	5.6
Z	289,717	5,309,463	6.0
AA	289,805	5,309,293	11.7
AB	290,342	5,308,551	14.0
AC	290,383	5,308,467	15.8
AD	293,700	5,304,262	7.8
AE	287,515	5,303,410	107.0
AF	284,058	5,304,377	10.8
AG	284,024	5,304,383	16.7
AH	284,000	5,304,413	17.8
AI	283,982	5,304,459	17.0
AJ	283,971	5,304,480	16.9
AK	283,990	5,304,444	16.6
AL	284,075	5,304,564	7.0
AM	284,113	5,304,541	7.9
AN	284,134	5,304,523	8.0
AO	284,164	5,304,472	9.5
AP	284,195	5,304,490	12.0
AQ	284,158	5,304,427	7.0
AR	284,237	5,304,396	12.0
AS	284,040	5,304,247	27.6
AT	284,032	5,304,174	20.4

ID	Easting (m) *	Northing (m)	Elev. (m)
AU	283,910	5,304,079	49.2
AV	283,969	5,304,132	34.6
AW	284,027	5,304,039	15.9
AX	284,029	5,304,132	20.7
AY	283,965	5,304,102	35.0
AZ	284,009	5,303,951	11.7
BA	283,982	5,303,977	15.2
BB	284,023	5,303,987	12.3
BC	284,013	5,303,965	12.3
BD	284,290	5,304,354	10.0
BE	284,319	5,304,342	11.0
BF	284,345	5,304,314	10.3
BG	284,413	5,304,191	10.5
BH	284,414	5,304,106	9.0
BI	290,196	5,309,771	22.6
BJ	290,062	5,309,581	4.0
BK	290,048	5,309,540	1.0
BL	290,514	5,309,609	73.0
BM	287,003	5,298,849	1.6
BN	287,550	5,297,549	2.9
BO	287,595	5,297,518	2.7
BP	287,738	5,297,521	1.0
BQ	288,235	5,297,308	3.0
BR	289,459	5,295,522	7.4
BS	292,524	5,295,745	9.3
BT	277,597	5,296,718	14.0

ID	Easting (m) *	Northing (m)	Elev. (m)
BU	276,091	5,302,826	15.6
BV	279,964	5,292,344	50.0
BW	291,777	5,308,929	7.1
BX	289,130	5,304,336	110.0
BY	284,009	5,309,011	115.0
BZ	289,696	5,309,498	5.3
CA	290,163	5,309,585	0.0
CB	283,605	5,309,797	105.0
CC	284,425	5,304,185	13.8
CD	284,039	5,304,123	18.9
CE	283,433	5,304,130	41.9
CF	282,180	5,304,634	18.4
CG	281,310	5,304,681	9.0
CH	281,483	5,304,915	33.0
CI	280,661	5,305,182	4.0
CJ	279,996	5,304,840	5.8
CK	277,153	5,296,693	18.7
CL	276,722	5,295,642	8.7
CM	275,849	5,294,952	40.0
CN	276,352	5,294,423	6.0
CO	277,567	5,289,898	6.1
CP	276,852	5,289,006	9.0
CQ	293,701	5,304,255	8.1
CR	277,768	5,303,790	49.6

* UTM, WGS84, Zone 22N

3.0 Shadow Flicker Analysis Results and Discussion

Figure 1 shows the results of the modeling and the spatial extent of the 30 shadow hours per year threshold level. Receptor specific results are provided for in Table 5.

The results of the theoretical case indicate that 4 of the 96 modeled receptors (M, N, AE and BX) would experience shadow flicker. Pseudo receptor AE would experience 125:58 and BX would experience 20:18 of shadow flicker per year. As receptors AE and BX are pseudo receptors, the only shadow impact on existing dwellings is expected at receptors M and N located on the north side of Deer Harbour. Receptor M and N are expected to receive 17:12 and 6:17 respectively of shadow flicker under the theoretical case scenario.

When the realistic case is considered, the total amount of shadow flicker is reduced as the presence of cloud is considered in the analysis. The pseudo receptors AE and BX are expected to receive 34:35 and 5:23 on an annual basis respectfully. Receptors M and N are expected to receive a cumulative total of 4:12 and 1:29 of shadow flicker per year.

The realistic case scenario provides a more comprehensive analysis as the assumptions in the theoretical case are conservative. By applying monthly sunshine probabilities, a more precise annual result can be generated, however the maximum shadow flicker per day cannot be calculated. This is due to using monthly sunshine probabilities which cannot be scaled to minute time steps. The realistic case results show that two dwellings modeled as receptors (M and N) are expected to experience shadow flicker that are below the 30 hour per year threshold (Table 5).

Pseudo receptor AE is expected to receive more than the 30 hour per year maximum. This is an expected outcome as the site is located relatively close to the proposed wind project (590 m). Proposed turbine site HAT-07 is expected to create shadow flicker at the location daily at approximately 10:00 am from November to early February. Turbines at sites HAT-06, HAT-08 and HAT-09 are also expected to have short duration shadow impacts in the mornings during the fall and spring. If this receptor was an actual dwelling, a turbine/day/time specific curtailment regime could be integrated into the turbine control software to limit shadow flicker impact at this receptor.

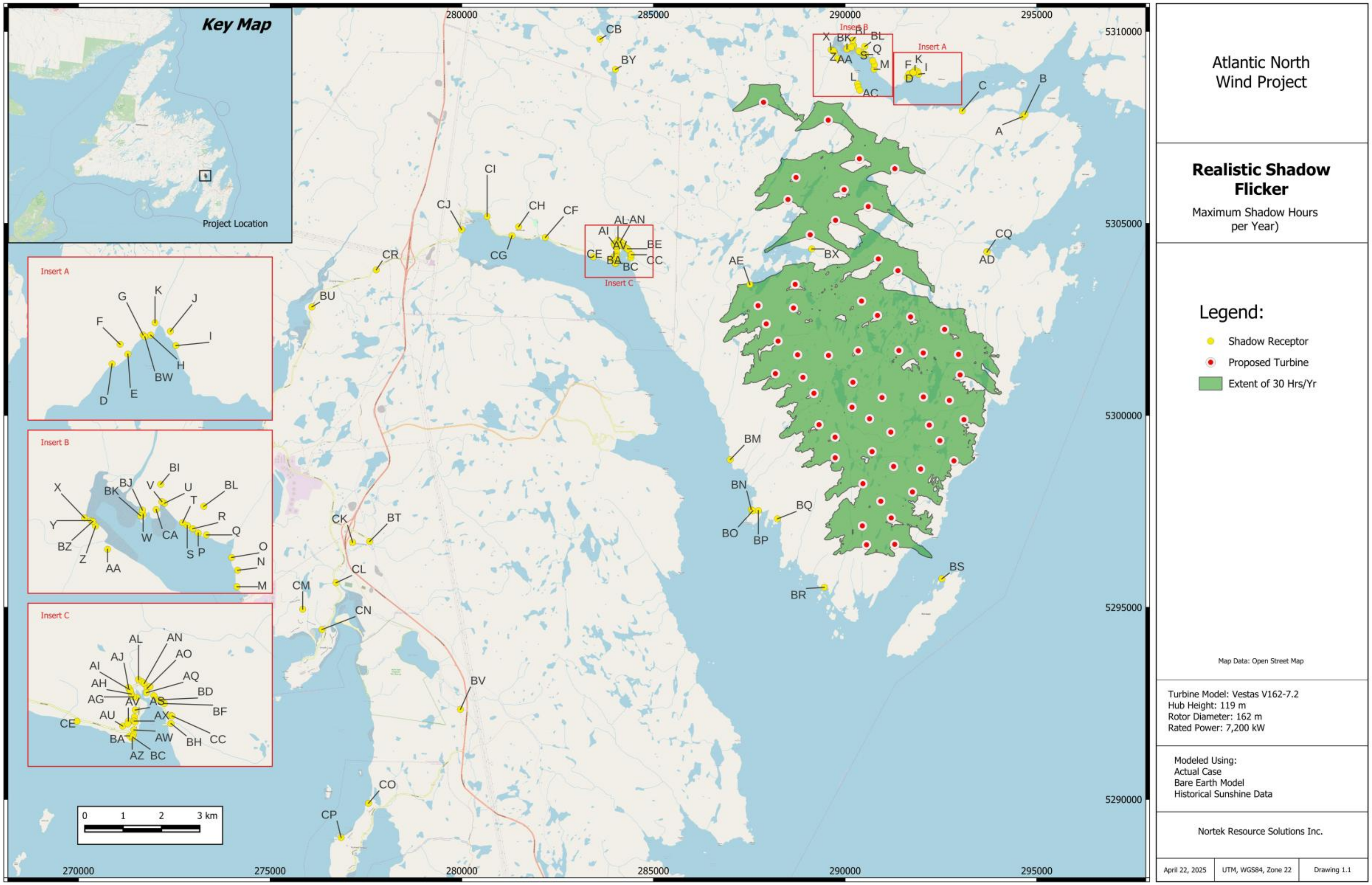

Figure 1: Shadow Flicker per Year Based on the Realistic Scenario for the Proposed North Atlantic Wind Farm.

Table 5: Predicted Shadow Flicker for Local Receptors Based on Theoretical and Realistic Case Scenarios.

	Theoretical Case		Realistic Case
Receptor ID	**Shadow Hrs per Year**	**Max. Shadow Minutes per Day**	**Shadow Hrs per Year**
A	0:00	0:00	0:00
B	0:00	0:00	0:00
C	0:00	0:00	0:00
D	0:00	0:00	0:00
E	0:00	0:00	0:00
F	0:00	0:00	0:00
G	0:00	0:00	0:00
H	0:00	0:00	0:00
I	0:00	0:00	0:00
J	0:00	0:00	0:00
K	0:00	0:00	0:00
L	0:00	0:00	0:00
M	17:12	0:23	4:12
N	6:17	0:16	1:29
O	0:00	0:00	0:00
P	0:00	0:00	0:00
Q	0:00	0:00	0:00
R	0:00	0:00	0:00
S	0:00	0:00	0:00
T	0:00	0:00	0:00
U	0:00	0:00	0:00
V	0:00	0:00	0:00
W	0:00	0:00	0:00
X	0:00	0:00	0:00
Y	0:00	0:00	0:00
Z	0:00	0:00	0:00
AA	0:00	0:00	0:00
AB	0:00	0:00	0:00
AC	0:00	0:00	0:00
AD	0:00	0:00	0:00
AE	125:58	1:06	34:35
AF	0:00	0:00	0:00
AG	0:00	0:00	0:00
AH	0:00	0:00	0:00
AI	0:00	0:00	0:00
AJ	0:00	0:00	0:00

	Theoretical Case		Realistic Case
Receptor ID	Shadow Hrs per Year	Max. Shadow Minutes per Day	Shadow Hrs per Year
AK	0:00	0:00	0:00
AL	0:00	0:00	0:00
AM	0:00	0:00	0:00
AN	0:00	0:00	0:00
AO	0:00	0:00	0:00
AP	0:00	0:00	0:00
AQ	0:00	0:00	0:00
AR	0:00	0:00	0:00
AS	0:00	0:00	0:00
AT	0:00	0:00	0:00
AU	0:00	0:00	0:00
AV	0:00	0:00	0:00
AW	0:00	0:00	0:00
AX	0:00	0:00	0:00
AY	0:00	0:00	0:00
AZ	0:00	0:00	0:00
BA	0:00	0:00	0:00
BB	0:00	0:00	0:00
BC	0:00	0:00	0:00
BD	0:00	0:00	0:00
BE	0:00	0:00	0:00
BF	0:00	0:00	0:00
BG	0:00	0:00	0:00
BH	0:00	0:00	0:00
BI	0:00	0:00	0:00
BJ	0:00	0:00	0:00
BK	0:00	0:00	0:00
BL	0:00	0:00	0:00
BM	0:00	0:00	0:00
BN	0:00	0:00	0:00
BO	0:00	0:00	0:00
BP	0:00	0:00	0:00
BQ	0:00	0:00	0:00
BR	0:00	0:00	0:00
BS	0:00	0:00	0:00
BT	0:00	0:00	0:00
BU	0:00	0:00	0:00
BV	0:00	0:00	0:00

	Theoretical Case		Realistic Case
Receptor ID	**Shadow Hrs per Year**	**Max. Shadow Minutes per Day**	**Shadow Hrs per Year**
BW	0:00	0:00	0:00
BX	20:18	0:22	5:23
BY	0:00	0:00	0:00
BZ	0:00	0:00	0:00
CA	0:00	0:00	0:00
CB	0:00	0:00	0:00
CC	0:00	0:00	0:00
CD	0:00	0:00	0:00
CE	0:00	0:00	0:00
CF	0:00	0:00	0:00
CG	0:00	0:00	0:00
CH	0:00	0:00	0:00
CI	0:00	0:00	0:00
CJ	0:00	0:00	0:00
CK	0:00	0:00	0:00
CL	0:00	0:00	0:00
CM	0:00	0:00	0:00
CN	0:00	0:00	0:00
CO	0:00	0:00	0:00
CP	0:00	0:00	0:00
CQ	0:00	0:00	0:00
CR	0:00	0:00	0:00

4.0 Conclusion

The shadow flicker analysis based on the realistic case indicates that the modeled dwelling receptors are expected to receive less than 30 hours per year of shadow flicker. The realistic values range from 1:29 to 4:12 per year for existing receptors and 5:23 to 34:35 for the pseudo receptors. Pseudo receptor AE exceeds the threshold, however as it is not an actual dwelling and was included in the analysis because of the public consultation process. Mitigation of shadow flicker can be accomplished by developing turbine specific curtailment schedules during conditions that cause shadow flicker at a receptor. This would be the solution, if required for pseudo receptor AE.

These modeled results indicate that the proposed wind project meets the current guidelines as accepted by the Newfoundland and Labrador Department of Environment and Climate Change for existing receptors.

5.0 References

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